



# Nutrient Management Technologies and the Role of Organic Matrix-Based Slow-Release Biofertilizers for Agricultural Sustainability: A Review

Indra Jeet Chaudhary<sup>1</sup>, Ajay Neeraj<sup>1</sup>, Mohd Arshad Siddiqui<sup>1</sup>, Vivek Singh<sup>2</sup>

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## ABSTRACT

Natural soil containing nutrients (like nitrogen, phosphorus, calcium and potassium) allows plants to grow. The deficiency of nutrients in soil reduced the growth and development of plants. When the nutrient level is too low, the plant cannot function properly and then fertilizers provide sufficient nutrients to plants. Nowadays the farmer applied various kinds of synthetic and organic and some special class of microbial fertilizers for more production of agricultural crops. Excess use of chemical fertilizers caused nutrient leaching problems and also pollutes soil, water and air environment. However, chemical fertilizers are expensive, non-eco-friendly, cause eutrophication, reduce organic matter and microbial activity in the soil and are hazardous to health. Therefore, Slow-release biofertilizers are also produced by the technical intermediations that breakdown the nutrients and make them available to the plants for a longer duration. These fertilizers play an important role in improving the growth and development of plants, thereby mitigating environmental pollution and helping in sustainable agriculture. The efficacy of slow-release biofertilizers can be enhanced plant growth and productivity and manage the nutrient leaching from soil and also control water pollution.

**Key words:** Biofertilizers, Eco-friendly, Environmental pollution, Nutrient leaching, Slow-release biofertilizer.

Nutrient efficiency is a worldwide problem in agricultural rich countries. Now, these days agricultural productivity depends on doses of fertilizers including organic or inorganic (Shah *et al.* 2019a,b). Fertilizers are providing necessary nutrients to plant growth and development. A fertilizer is synthetic chemical-based substances that immediately enhance plant growth and soil fertility. It may also increase water retention and filter any excess liquid, hence enhancing soil effectiveness. Chemical fertilizer containing three major macronutrients, potassium, phosphorus and nitrogen and may also add secondary nutrients such as sulfur, magnesium and calcium to the soil or growing media (Elayaraja and Sathiyamurthi 2020). The excessive use of synthetic chemical fertilizers is no more considered as ecologically suitable.

The alternative nutrient sources e.g. organic fertilizers and plant growth-promoting microorganisms (epically PGPR) have been applied to reduce a load of chemical fertilizers (Adesemoye *et al.* 2009; Shaukat *et al.* 2006; Rawat *et al.* 2010). It has been knowing that the unnecessary use of inorganic fertilizers is unsustainable for any farming practices from economic and ecological points of view (Shekoofa and Emam 2008; Singh *et al.* 2006; Chaudhary and Singh 2018). Nutrient sources like inorganic, organic and biofertilizers utilization is the major components of sustainable agriculture. These components have several advantages such as enhanced the essential nutrients, improves the soil's physical, chemical and biological properties and also conserving the soil moisture-holding capacity and fixed the atmospheric nitrogen and mobilized from unavailable to available forms of nutrients

<sup>1</sup>School of Environment and Sustainable Development, Central University of Gujarat, Gandhinagar-382 030, Gujarat, India.

<sup>2</sup>Department of Horticulture, H.N.B. Garhwal University, Srinagar Garhwal-246 174, Uttarakhand, India.

**Corresponding Author:** Indra Jeet Chaudhary, School of Environment and Sustainable Development, Central University of Gujarat, Gandhinagar-382 030, Gujarat, India.  
Email: indrajeet.cug@gmail.com

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(Chaudhary and Singh 2018; Singh *et al.* 2019).

Soil and water management is important to reduce the use of fertilizers and to increase the efficiency and yield of nutrients which achieve the goal of sustainable agriculture (Singh *et al.* 2019). The mineral nutrient play as important role in the growth of plants and fertilizers promote the availability of nutrients to plant from soil to root, shoot of plants. Various kinds of nutrients play an important role in plant growth and rhizospheric soil. As nutrient nitrogen plays an important role in the transformation of carbohydrates into proteins and promotes the formation of protoplasm in cells. Enough supply of nitrogen mineral in plants associate good vegetative growth and improves the capacity of the plant to higher productivity (Bhangu *et al.* 2019; Kumar *et al.* 2012; Chaudhary and Singh 2018; Singh *et al.* 2019). Phosphorus involves as a key component of nucleic acid, phospholipids

and several other enzymes. Phosphorus plays a vital role in the plant for the transformation of energy within the plant body and it is very effective in early root growth and development (Chaudhary and Singh 2018; Malhotra *et al.* 2018). While, potassium play their role in planting or and different disease resistance capacity to plants and acts as an activator of several enzymes like pyruvic kinase, cytoplasmic enzymes, etc. The bio-fertilizers are organic in origin and therefore are completely safe for soil and also the human point of view. It is responsible for the persistent effect on the metabolic events of the plant system and also enhances the growth and yield of plants (Ashley *et al.* 2006; Wang *et al.* 2013; Shah *et al.* 2019a,b).

Slow-release biofertilizers are eco-friendly safe fertilizers. It is produced by technical intermediation which breakdown nutrients and make them available to plant for a longer time (Emilsson *et al.* 2007; Kumar *et al.* 2012; Grant *et al.* 2012). These fertilizers improving the growth and yield of the agricultural crop as a sustainable way and also mitigate environmental pollution (soil, water and air). Although biofertilizer offers an economically and ecologically sound alternative to the chemical fertilizers for realizing the ultimate goal of increased productivity, its efficacy is significantly low in relation to the crop yield when compared with the recommended dose of chemical fertilizers (Wu *et al.*, 2008). It has been demonstrated that chemical fertilizers entrapped in organic matrix of cow dung, clay soil, neem leave powder and acacia gum (non-toxic and biodegradable organic materials) as a carrier prepared in form of super granules enhance growth, productivity and yield of rice (Dahiya *et al.* 2004; Kumar *et al.* 2012; Chaudhary and Singh 2018).

Now, these day chemical fertilizers are a knowledgeable source of environmental pollution which caused serious problem to water, soil and air environment. Organic and microbial-based biofertilizers are environmentally safe and improving the soil properties and plant growth. While slow-release biofertilizers enhance the plant growth and maintain the rhizospheric soil properties and manage the nutrient leaching from soil thereby indirectly mitigating environmental pollution (soil, water and air pollution) and helping in sustainable agriculture.

### **Chemical fertilizers and its impact on soil, water and air environment**

Chemical fertilizer is a synthetic chemicals form combined with primary macronutrient such as nitrogen, phosphorus and potassium as well as micronutrient and additives for plants. They can enter the food chain through plant. Thus, Excessive uses of chemical fertilization lead to water, soil and air pollution. Resulting large number of environmental problems because some fertilizers are also containing heavy metals. Fertilization increases the nutrient uptake capacity of plants from the soil and obtains a better quality product of agricultural activities. The fertilizer industry is considered to be a source of natural radionuclides and heavy metals as a potential source. It contains a large number of heavy metals

(Hg, Cd, As, Pb, Cu, Ni and Cu) and natural radionuclide such as  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{210}\text{Po}$  (FAO 2009; Sönmez *et al.* 2007). The agricultural plants also having a higher absorbance capacity of heavy metal (Singh *et al.* 2019).

### **Effect of fertilizers on soil, water and air**

Soil having strong buffering power, therefore, the effect of chemical fertilizers on the soil is not immediately noticeable. Over time it states that emerge from pollution, soil fertility, soil degradation and to decline of the current element. In other words toxic substances accumulation by plant especially edible plants causing a negative effect on humans and animals. The structure of the soil is a very important factor in the productivity of crops. Mechanically, the fertilizing soil, just as in the worsening of the structure is caused by industrial emissions. Especially chemicals compound like  $\text{NaNO}_3$ ,  $\text{NH}_4\text{NO}_3$ ,  $\text{KCl}$ ,  $\text{K}_2\text{SO}_4$ ,  $\text{NH}_4\text{Cl}$  defeat the structure of the soil, such as fertilizers and high-quality effective product. The higher level of sodium and potassium-containing fertilizers caused a negative impact on soil, pH, soil structure and the increasing feature of acid irrigation. While continuous use of nitrogen fertilizers decreased soil pH and declining the efficiency of field crops. Application of fertilizers in the soil leads to increase pH and increases in soil and plant seedling pH sudden drop and yield and quality were also drop and caused harmfulness.

Research in the province of Rize in the territory of our country, one-way ammonium sulfate fertilization of tea, actually led to an increase in acidity of soils with low pH. Today 85% of the territory has dropped below pH 4 which is considered as the critical level. In new over the last twenty-five years as a result of nitrogen fertilization of potatoes grown in 100-fold increased acidity of the soil pH has fallen to 2. Granting the land, excessive nitrogen fertilizers *Rhizobium* sp. activities, such as symbiotic nitrogen-fixing microorganisms is negatively affected. In this case, the part of the air plugs to benefit from the free nitro. In addition, more nitrogenous fertilizers limit the activities of nitrifying bacteria. Thus, the cost of the second nitrogen source is damaged (Topbaş *et al.* 1998). Given large amounts of potassium fertilizers in the soil of Ca and Fe with Zn disrupt the balance of nutrients by the plants and prevent the receipt. However, the negative effects on organisms, given the variety of worms and soil mite has been the devastating and lethal effects.

The contamination of water due to the application of fertilizers becomes a serious problem nowadays. Fertilizers especially chemical fertilizers containing nitrogen, phosphorus and potassium caused harmful effects to the water body. This mineral reaches a water body that caused eutrophication and affects the natural properties of water. Soil nutrients in the agricultural area reached the water environment by Drainage, leaching and flow. Application of fertilizers in soil converted to nitrogen in nitrate, nitrite and ammonium while phosphorus is converted as phosphate in the form which highly mobilized. Nitrate converted through nitrification by microorganisms and due to negatively charge

of nitrate can reach groundwater. In ideal condition plants used only 50% of nitrogenous fertilizers applied to the soil. Among them about 2-20% lost by evaporation, 15-25% react organic compounds in the clay soil and the remaining 2-10% inhibit surface and groundwater (Korkmaz 2007; Sönmez *et al.* 2008). The majorities of nitrogenous fertilizer products is not absorbed and inhibit both underground and surface water.

Eutrophication is one of the most important negative effects of intensive fertilizer in water bodies. An increasing amount of nitrogen and phosphorous in water resultants increased the aquatic plants and algae formation and degradation of water quality. eutrophication caused oxygen-free environment on the bottom layer and it is not suitable for drinking and water supply and also caused reduction of living species in the aquatic environment like fish kills, propagation of annoying species, odor problem and unsuitable for recreation (Sönmez *et al.* 2008; Tayyar 2011).

The concentration of nitrate in groundwater should be considered as a global problem. Thereby about 22% of cultivated areas in Europe for the international recommended drinking water nitrate concentration found in groundwater above ( $\geq 11.3$  mg/L) and in European Countries,  $\text{NO}_3\text{-N}$  concentration value was found 23 mg/L and in the USA it is 45 mg/L. the concentration of  $\text{NO}_3$  and  $\text{NH}_4^+$ , in Nottingham, United Kingdom exceeds the stated limits. It's vulnerable to contamination from numerous sources from urban and industrial activities. Nitrate from drinking water body absorbed by kidney in intestinal tract 4-12 hours. The salivary gland concentrate nitrate resultant mouth reduced nitrite in an anaerobic environment.

Nitrates from drinking water of the body are absorbed in the intestinal tract 4-12h and is excreted by the kidneys. The mechanism, as well as the salivary glands, can concentrate nitrate. As a result, the mouth is reduced to nitrite in the anaerobic environment. It is possible to examine the toxicological effects of nitrate in three stages. The primary toxic effect of nitrate concentrations in drinking water of 50 mg  $\text{NO}_3^-$  /L exceeds the value of the bowel in adults, digestive and urinary systems, inflammation is seen. Seconder toxicity, high nitrate concentration in drinking water caused disease in infant's methemoglobinemia. Stomach acid does not occur in infants younger than six months. In this environment, nitratennitrite reacts with hemoglobin in the blood is minimized methemoglobin consists of nitrite in the digestive system. Meanwhile, iron contained in hemoglobin and blood oxygen transport function lost. As a result, infants are found strangled to death.

In the agricultural sector fertilizers is one of the most important inputs of air pollution worldwide. When fertilizers are applied in an insufficient rate the productivity and quality of crop are losses. When applied too much caused air pollution by nitrogen oxide with precursor gases ( $\text{NO}$ ,  $\text{N}_2\text{O}$ ,  $\text{NO}_2$ ) emissions. Now these days some gases in the atmosphere known as vapour, carbon dioxide, methane, hydrogen sulfide, chloroflouro hydrocarbon and halon and

also tropospheric ozone associated with these compounds caused the greenhouse effect. Globally, atmospheric  $\text{N}_2\text{O}$  increased from 0.2 to 0.3% each year due to excessive use of nitrogenous fertilizers, especially nitrate level of the plant caused human health reaches by eaten leafy vegetables (Atılğan *et al.* 2007). Calcareous and alkaline soils especially applied to the soil surface structure and ammonium fertilizers with urea can result in evaporation of  $\text{NH}_3$ . Evaporation of ammonia a large number of soil and environmental factors can be controlled and directly proportional to the concentration of ammonia in the soil solution. Ammonia emission especially from fertilized land to leads depositing on ecosystems and vegetation damage. Ammonia may be oxidized and turns into nitric acid, sulphuric acid from industrial sources, create acid rain after the chemical transformations. Acid rain can damage vegetation and also, it can damage organisms that they live in both lakes and reservoirs (Shaviv 2000; Savci 2012).

### Biofertilizers

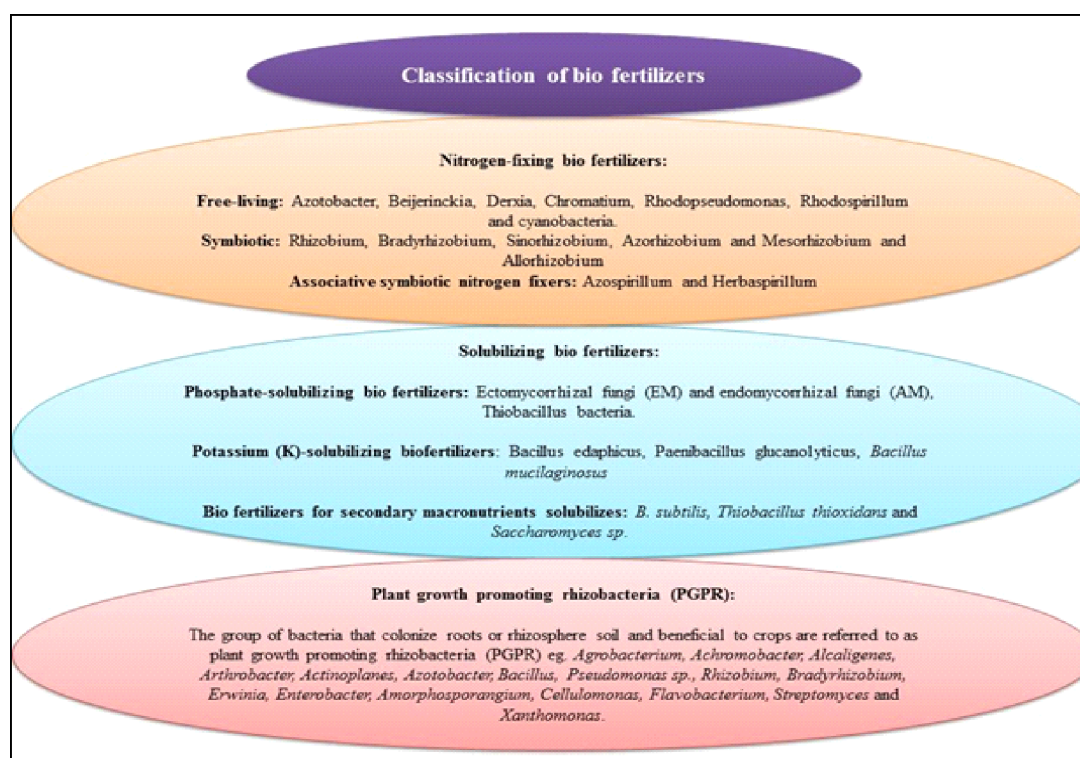
Bio-fertilizer is simply a substance which contains living microorganisms which when applied to the soil, a seed or plant surface colonizes the rhizosphere and promotes growth by increasing the supply or availability of nutrients to the host plant (Vessey 2003). A bio-fertilizer is a modernized form of organic fertilizer into which beneficial microorganisms have been incorporated (Swathi 2010). In a large sense, the term biofertilizer may be used to include all organic resources for plant growth which are rendered in available form for plant absorption through microorganisms or plant associations or interactions (Khosro and Yousef 2012).

### Classification and role of biofertilizers

Biofertilizer contains living microorganisms increasing the availability of primary nutrients to plant. Several microorganisms and their association with crop plants are being exploited in the production of biofertilizers. On the basis of nature and function as Symbiotic, Non symbiotic and nutrient solubilizers biofertilizers were classified as various types (Fig 1).

### Role of Rhizobium

Nitrogen fixation is a key factor in low-input agricultural systems to sustain long-term soil fertility. Plant-bacteria interactions in the rhizosphere are the determinants of plant health and soil fertility. The climatic conditions of arid and semiarid regions are often characterized by hot, dry summers, sub-humid monsoons and cold dry winter. The climatic conditions in this region restrict the build-up of soil organic matter and soils are generally deficient in nitrogen. Knowledge of rhizobial diversity from arid and semiarid areas is essential to improve their nutrient-poor fertility status. Soils of these regions often suffer from moisture stress, salinity, unfavourable pH, nutrient deficiency, mineral toxicity, temperature extremes, plant diseases, trace element deficiencies, etc., which inhibit nodulation and impose limitations on the vigor of the host legume. The tolerance to high levels of salinity and the survival and persistence in



**Fig 1:** Classification of biofertilizers.

harsh desert conditions make these rhizobia highly valuable inocula to improve the productivity of the leguminous plants cultivated under extreme environments. This functional diversity and tolerance to extreme environments displayed by efficient rhizobial isolates alone or co-inoculation with PGPR can be effectively utilized for improving legume crop production and productivity in arid and semiarid regions (Singh *et al.* 2017).

#### Role of *Azotobacter*

*Azotobacter* improves seed germination and has a beneficiary response on Crop Growth Rate (CGR). It helps to increase nutrient availability and to restore soil fertility for better crop response. It is an important component of an integrated nutrient management system due to its significant role in soil sustainability. *Azotobacter* species are Gram-negative, free-living, aerobic soil dwelling, oval or spherical bacteria that form thick-walled cysts (means of asexual reproduction under favorable condition (Salhia 2013)). There are around six species in the genus *Azotobacter* some of which are motile by means of peritrichous flagella; others are not (Martyniuk and Martyniuk 2003). They are typically polymorphic and their size ranges from 2–10 µm long and 1–2 µm wide (Salhia 2013). *A. chroococcum* is the first aerobic free-living nitrogen fixer. These bacteria utilize atmospheric nitrogen gas for their cell protein synthesis. This cell protein is then mineralized in the soil after the death of *Azotobacter* cells thereby contributing towards the nitrogen availability of the crop plants. *Azotobacter* spp. is sensitive to acidic pH, high salts and temperature. *Azotobacter* has

beneficial effects on crop growth and yields through, biosynthesis of biologically active substances, stimulation of rhizospheric microbes, producing phytopathogenic inhibitors. Modification of nutrient uptake and ultimately boosting biological nitrogen fixation (Somers *et al.* 2004). Besides being quite expensive and making the high cost of production, chemical fertilizers have an adverse effect on soil health and microbial population. In such a situation, biofertilizer can be the best alternative for enhancing soil fertility. Being economical and environmentally friendly, biofertilizers can be used in crop production for better yield (Chen 2006; Lenart 2012; Nagananda *et al.* 2010). Similarly, microbial products are considered safer, self-replicating, target-specific, which is regarded as a major component of integrated nutrient management from a soil sustainability perspective (Jnawali *et al.* 2015).

#### Role of *Azospirillum*

*Azospirillum* as the most important genera of PGPR is able to colonize the roots of several plant species and increase their growth by the production of different metabolites, including plant hormones (Peng *et al.* 2006; Mehnaz *et al.* 2007; Saharan and Nehra 2011). Usually, the formation of *Azospirillum* in the rhizosphere results in the advancement of plant development. They develop an associative symbiotic relationship with graminaceous plants. Apart from nitrogen fixation, growth-promoting substance production (IAA), disease resistance and drought tolerance are some of the additional benefits of immunization with *Azospirillum*. *Azospirillum* represents the best characterized genus of



plant growth-promoting rhizobacteria. Other free-living diazotrophs repeatedly detected in association with plant roots, include *Acetobacter diazotrophicus*, *Herbaspirillum seropedicae*, *Azoarcus spp.* and *Azotobacter*. Four aspects of the *Azospirillum* plant root interaction are highlighted: natural habitat, plant root interaction, nitrogen fixation and biosynthesis of plant growth hormones. Each of these aspects is dealt with in a comparative way. *Azospirilla* are predominantly surface colonizing bacteria, whereas *A. diazotrophicus*, *H. seropedicae* and *Azoarcus sp.* are endophytic diazotrophs. The attachment of *Azospirillum* cells to plant roots arises in two steps. The polar flagellum, of which the flagellin was shown to be a glycoprotein, mediates the adsorption step (Steenhoudt and Vanderleyden 2000).

### Role of Cyanobacteria

Both free-living, as well as symbiotic cyanobacteria (blue green algae), have been harnessed in rice cultivation in India. Cyanobacteria (blue-green algae) are a diverse group of prokaryotes, having oxygenic photosynthesis and are amongst the most successful and oldest life forms present on the planet earth. They comprise about 150 genera and 2,000 species ranging from unicellular, colonial, filamentous to branched filamentous forms and are divided into 5 subsections i.e. Chroococcales, Pleurocapsales, Oscillatorales, Nostocales and Stigonematales (Boone and Castenholz 2001). They are ubiquitous in their distribution and grow in all sorts of aquatic and terrestrial environments exhibiting a wide range of temperature, salinity, water potential, pH and irradiance. Their widespread distribution reflects a broad spectrum of physiological properties and tolerance to environmental stresses. The economic importance of cyanobacteria primarily lies in their agronomic importance as biofertilizers due to the  $N_2$ -fixing ability that helps them to grow successfully in habitats where little or no combined nitrogen is available (Singh *et al.* 2013a). Nostocacean cyanobacteria are broadly characterized by their unbranched filaments and the presence of heterocysts which are the sites of nitrogen fixation. They are naturally found in most paddy soils and improve the fertility and texture of the soil in addition to the rice yield at no cost. Increasing food demand has largely amplified the utilization of chemical fertilizers to achieve a high and significant rise in crop yield. However, careless and overuse of these fertilizers is leading to the pollution of both soil and water. Cyanobacteria offer an economically attractive and environment-friendly alternative to chemical fertilizers which increase the soil productivity both directly and indirectly (Singh *et al.* 2013b; Thatoi *et al.* 2013). This review comprises a precise discussion about the agricultural importance of cyanobacteria with special reference to crop plants.

### Role of Azolla

Azolla is a free-floating water fern having importance capability to fix nitrogen which is present in the leaf cavity of the fern. Azolla is a rich source of protein and essential amino acids (nitrogen 4-5%, phosphorous 0.5-0.9%) and contains several

vitamins such as vitamin-A, vitamin B-12 and beta carotene. It is also rich in minerals such as Calcium, Phosphorous, Potassium, Magnesium, Copper and Zinc etc. The protein composition of Azolla is 25-35% on a dryweight basis (Setiawati *et al.* 2018). The growth of Azolla in the tropics is best during the rainy season when productivity is high. Low productivity of Azolla occurs in the dry season. The high environmental temperature during the dry season induces the increase of insect infestation and fungal infection on Azolla (Setiawati *et al.* 2018). The most common mode of application of Azolla in the field is as green manure or as a dual crop along with rice. In case of application as green manure Azolla collected directly from ponds is applied in the field. Azolla thus incorporated decomposes within about 8-10 days and releases the fixed nitrogen (Yadav *et al.* 2014). To supply organic matter from Azolla and save when the production of Azolla is abundant then Azolla needs to be dried or composted. The lignin content of dry Azolla was 21% and this was higher than fresh Azolla lignin of 18%, making the mineralization of dried Azolla more difficult. Composting Azolla produces mineralization of organic matter, produces more available nutrient content. Composted Azolla then made powder Preparation of compost powder *A. pinata* is done to reduce the constraints of the voluminous application of organic fertilizers and improve the efficiency of its use. Composted Azolla is then made into powder and passes through 100 mesh sieve, can improve the efficiency of its use. Continuous applications of Azolla increase the organic nitrogen content of the soil significantly. Increased cellulolytic and urea hydrolyzing activities in addition to a significant increase in the population of heterotrophic bacteria were recorded (Setiawati *et al.* 2018). Increased soil urease and phosphatase activity have also been observed due to the incorporation of Azolla. The significantly high mean value of nitrogen as a result of high N content in Azolla is reported by Bhuvaneshwari (2012).

### Role of AM fungi

Mycorrhizal fungi allow plants to draw more nutrients and water from the soil. They also increase plant tolerance to different environmental stresses. Moreover, these fungi play a major role in soil aggregation process and stimulate microbial activity. Soil microorganisms such as arbuscular mycorrhizal fungi (AMF or AM fungi) represent a key link between plants and soil mineral nutrients. Thus, they are collecting growing interest as natural fertilizers. AMF are obligate symbiosis, belonging to the phylum Glomeromycota (Schüßler 2001), which form mutualistic symbioses with about 80% of land plant species, including several agricultural crops. They provide the host plant with mineral nutrients and water, in exchange for photosynthetic products (Smith and Read 2008). The AMF mycelium that emerges from the root system can acquire nutrients from soil volumes that are inaccessible to roots (Smith *et al.* 2000). Furthermore, fungal hyphae are much thinner than roots and are therefore able to penetrate smaller pores (Allen 2011). Carbohydrates and mineral nutrients are then

exchanged inside the roots across the interface between the plant and the fungus. AM fungal hyphae exclusively colonize the root cortex and form highly branched structures inside the cells, i.e., arbuscules, which are considered the functional site of nutrient exchange (Balestrini *et al.* 2015). Thus, AMF can alleviate the limitation in plant growth caused by an inadequate nutrient supply (Nouri *et al.* 2014). It has recently been suggested that, in natural environments, a non mycorrhizal condition should be viewed as abnormal for the majority of species, although there is a marked diversity among AM fungal communities belowground, depending on plant species diversity, soil type and season, or a combination of these factors (Smith and Smith 2012). In addition to an improved nutritional supply, AM interactions provide other benefits to plants, such as improved drought and salinity tolerance and disease resistance (Pozo and Azcón-Aguilar 2007; Porcel *et al.* 2011; Augé *et al.* 2015). Although several works have been devoted to studying the influence of AM symbiosis on the plant response to abiotic stress (such as drought, salinity and flooding) in the last few years, the mechanisms responsible for the increased plant tolerance to stress have yet to be fully elucidated (Augé *et al.* 2015; Bárzana *et al.* 2012; Ruiz Lozano *et al.* 2012; Bárzana *et al.* 2015; Saia *et al.* 2014).

#### **Role of Silicate solubilizing bacteria (SSB)**

Silicate solubilizing bacteria (SSB) can play an efficient role not only in solubilizing insoluble forms of silicates but also potassium and phosphates, hence increasing soil fertility and thereby enhancing plant growth and productivity. Silicon (Si) is the eighth-most abundant element in the universe and second most abundant in the Earth's crust, which attracted attention in crop production and recognized as a beneficial nutrient (Heckman 2012; Bakhata *et al.* 2018). Due to the increasing knowledge of Si influenced the plant growth promotion and plant protection and also confers a multitude of beneficial effects on plant growth and development. Soluble Si is known to enhance the growth, development and yield and also imparting tolerance to various biotic and abiotic stresses of several plant species (Epstein 2009). Numerous reports suggest that silicon nutrition alleviates abiotic stresses including drought, high temperatures, metal toxicity and biotic stresses (Datnoff *et al.* 2009). It also facilitates the uptake of micro nutrients like, P, Mg, K, Fe, Cu and Zn (Xue *et al.* 2014; Singh *et al.* 2019). The beneficial properties of Si against biotic and abiotic stresses and other valuable effects can result in Si being a critical component of sustainable agriculture and food production.

#### **Role of Plant growth-promoting rhizobacteria (PGPR)**

Rhizobacteria that exert beneficial effects on plant growth and development are referred to as Plant Growth Promoting Rhizobacteria (PGPR). Plant growth-promoting rhizobacteria is a group of free-living soil bacteria, which have the ability to promote growth and yield of crop plants by direct and indirect mechanisms. Agriculture is one of the human

activities that contribute most to the increasing amount of chemical pollutants via excessive use of synthetic chemical fertilizers and pesticides, which causes further environmental damage with potential risks to human health. Nitrous oxide ( $N_2O$ ) is an example of chemical pollutants produced by excessive use of nitrogen fertilizer and is a major source of greenhouse gases causing global warming. Moreover, 74% of total U.S.  $N_2O$  emissions in 2013 were accounted for by agricultural soil management, the largest single source Draft U.S. Greenhouse Gas Inventory Report 1990–2014. Apart from that, nitrogen fertilizers reduce biological nitrogen fixation in the soil. Farmers apply a high concentration of nitrogen fertilizers in the form of ammonium nitrate to fertilize their soil to grow crops. Due to the influx of ammonium, plants no longer need the symbiotic microbes to provide ammonium and this leads to the degree of symbiosis being diminished. Furthermore, nitrifying bacteria also take advantage of this excess ammonium and utilize it to produce nitrate. This high amount of nitrate is then utilized by denitrifying bacteria to produce  $N_2O$  and excess nitrate leaches into the groundwater (Galloway *et al.* 2008). Towards a sustainable agricultural vision, crops produced need to be equipped with disease resistance, salt tolerance, drought tolerance, heavy metal stress tolerance and better nutritional value. To fulfill the above desired crop properties, one possibility is to use soil microorganisms (bacteria, fungi, algae, etc.) that increase the nutrient uptake capacity and water use efficiency (Armada *et al.* 2014). Among these potential soil microorganisms, bacteria known as plant growth promoting rhizobacteria (PGPR) are the most promising. In this sense, PGPR may be used to enhance plant health and promote plant growth rates without environmental contamination (Armada *et al.* 2014). For decades, varieties of PGPR have been studied and some of them have been commercialized, including the species *Pseudomonas*, *Bacillus*, *Enterobacter*, *Klebsiella*, *Azobacter*, *Variovorax*, *Azospirillum* and *Serratia* (Glick 2012). However, the utilization of PGPR in the agriculture industry represents only a small fraction of agricultural practice worldwide (Bashan *et al.* 2014). This is due to the inconsistent properties of the inoculated PGPR, which could influence crop production. The successful utilization of PGPR is dependent on its survival in soil, the compatibility with the crop on which it is inoculated, the interaction ability with indigenous microflora in soil and environmental factors (Martinez-Viveros 2010). Another challenge is that the modes of action of PGPR are diverse and not all rhizobacteria possess the same mechanisms (Dey *et al.* 2004; Choudhary *et al.* 2011). These disadvantages limit the application of PGPR. Therefore, the competition between synthetic chemical fertilizers and PGPR as a biofertilizer is deemed redundant in the face of the global agricultural productivity needed to feed the booming world's population, which is predicted to escalate to 8 billion people by 2025 and 9 billion by 2050.

According to Nakkeeran *et al.* (2005), an ideal PGPR should possess high rhizosphere competence, enhance

plant growth capabilities, have a broad spectrum of action, be safe for the environment, be compatible with other rhizobacteria and be tolerant to heat, UV radiation and oxidizing agent. Considering the factors discussed above, the need for a better PGPR biofertilizer to complements skyrocketing agricultural food production as one of the crucial drivers of the economy has been highlighted. The inclusion of nano-encapsulation technology has been vital to the revolution of today's PGPR biofertilizers' formulation.

### Slow release bio fertilizers

The slow-release fertilizers are slow-acting and facilitate long term availability of the nutrients often harmonized with the physiological essential of plants and are reflected as one of the most feasible substitutes for the sustainable plant productivity (Sharma and Singh 2011; Chaudhary and Singh 2018). Convinced reports are accessible regarding use of slow-release fertilizers for oilseed crops, however, either the yield improved has not been found significant or the cost of fertilizers does not permit farmers in the countries like India to replace chemical fertilizers (Kumar *et al.* 2012). Organic matrix-based slow-release fertilizer increases plant growth, nitrate assimilation and seed yield of Indian mustard and is cost-effective (Sharma and Singh 2011).

A number of alternatives have been implemented during the last decades, e.g. biofertilizers, integrated plant nutrient system (IPNS) and farm yard manure (FYM), slow/controlled release fertilizers (Cong *et al.* 2011; Grant *et al.* 2012; Shah *et al.* 2019a,b ). The utilization of biological nitrogen fixation (BNF) technology can decrease the use of Urea-N, prevent the depletion of soil organic matter and reduce environmental pollution to a considerable extent (Choudhury and Kennedy 2004; Kennedy *et al.* 2004; Chaudhary and Singh 2018). Strains of *Azotobacter*, *Rhizobium*, *Bradyrhizobium*, *Azospirillum*, *Pseudomonas*, *Bacillus* and *Acetobacter* have been developed as biofertilizers. These bacteria exert beneficial effects on plant growth and development. It has been demonstrated that certain rice varieties respond positively to inoculation when selected diazotrophic strains from the sespecies were used as biofertilizer (Rodrigues 2008; Ferreira *et al.* 2010). Slow and controlled release fertilizers are also produced by the technical interventions which reduce the nutrient possess and provide nutrients to the plants for a comparatively longer duration. It plays an important role in improving fertilizers use efficiency by plants, thereby mitigating environmental pollution and sustainable agriculture (Zhao *et al.* 2010). Though, biofertilizers offer an economically attractive and ecologically sound alternative to the chemical fertilizers for realizing the ultimate goal of increased productivity, its efficacy is significantly low in relation to the crop yield when compared with the recommended dose of chemical fertilizers. Here, we have developed a low-cost, high efficient, sustainable organic matrix entrapped slow release biofertilizers, using local biodegradable agro waste like cow dung, clay soil, neem leaves easily available for Local production by small scale industries or by farmers. The

objective of this paper is to investigate the response of organic matrix entrapped biofertilizers on growth, yield and soil properties of rice plant.

### Microbial diversity in soil

Soil microbe is an important driver of the nutrients cycle. In the agroecosystem, soil provides important functions such as the turnover of organic material, cycling of nutrient and xenobiotics degradation and adsorption. Soil microbe can also promote crop growth by producing antibiotics and plant hormones and enhanced the availability of nutrients. The availability of nutrients to plant can be increased growth and productivity of agricultural crops (Bacon *et al.* 2015; Chaudhary and Singh 2018). Various researches have been conducted on the soil microbial community and its function in agricultural crop production. These investigation and identification have been attributed that ecosystem processes reflect as crop productivity (Ding *et al.* 2018), regulation of decomposition (Hartmann *et al.* 2015), nutrient cycling (Wagg *et al.* 2015) and protection of soil-borne pathogens (Van Bruggen *et al.* 2006). Some studies have revealed that agricultural practices have significant influences on soil microbial communities and composition, including the tillage regime, fertilization, monoculture, crop residue management and plant protection schemes (Degrunen *et al.* 2015; Xiong *et al.* 2015; Jiménez-Bueno *et al.* 2016; Ye *et al.* 2018). Hence, the soil microbial community could be removed to a positive organization for plant production and ecosystem sustainability by suitable agricultural practices (Hartmann *et al.* 2015).

Organic farming is one of the best practices for increasing the productivity of crop and maintenance of soil properties. Organic farming is beneficial for increasing environmental biodiversity such as animals, insects and butterflies as compared to conventional farming (Gomiero *et al.* 2011; Wang *et al.* 2016). Several studies suggested that an abundance of the microbial community was higher in organic farming than conventional soil practices (Hartmann *et al.* 2015; Xiong *et al.* 2015). The increments of microbial diversity could be correlated to reduced tillage, cover cropping and incorporation of organic fertilizers by improving soil organic carbon as the energy source of heterotrophic microbiota (Gomez *et al.* 2006; Sengupta and Dick 2015; Fernandez *et al.* 2016; Lupwayi *et al.* 2017). Furthermore, high microbial diversity has been related to high functional diversity in soil (Wagg *et al.* 2015), which may cause the important ecological processes mentioned above. In addition, most researchers studied the microbial community under different agricultural management practices with field crops such as rice (Ding *et al.* 2018; Gu *et al.* 2017) and wheat (Jiménez-Bueno *et al.* 2016), whereas little research has focused on vegetable cultivations (Bonanomi 2016). Specifically, we still have a limited understanding of the long-term effects of organic and conventional management on soil microbial communities under open-field and protected conditions.

### Nutrient leaching

Water-soluble nutrient leaching causes water pollution and also loss of mineral in the agricultural fields. Application of excess fertilizers and heavy rain and irrigation are the basic factors for nutrient losses. Soil structure, crop planting, type and application rates of fertilizers and other factors are taken into account to avoid excessive nutrient loss. Leaching may also refer to the practice of applying a small amount of excess irrigation where the water has a high salt content to avoid salts from building up in the soil (salinity control). Where this is practiced, drainage must also usually be employed, to carry away the excess water. Leaching is a natural environment concern when it contributes to groundwater contamination. As water from rain, flooding, or other sources seeps into the ground, it can dissolve chemicals and carry them into the underground water supply. Particular concern of hazardous waste dumps and landfills and, in agriculture, excess fertilizer, improperly stored animal manure and biocides (e.g. pesticides, fungicides, insecticides and herbicides) (Fig 2).

### Nitrogen leaching

Nitrogen is a common element in nature and an essential plant nutrient. Approximately 78% of the Earth's atmosphere is nitrogen ( $N_2$ ). The strong bond between the atoms of  $N_2$  makes this gas quite inert and not directly usable by plants and animals. As nitrogen naturally cycles through the air, water and soil it undergoes various chemical and biological transformations. Nitrogen promotes plant growth. Livestock then eats the crops producing manure, which is returned to the soil, adding organic and mineral forms of nitrogen. The cycle is complete when the next crop uses the amended soil (Ontario Ministry of Agriculture, Food and Rural Affairs).

To increase food production, fertilizers, such as nitrate ( $NO_3$ ) and ammonium ( $NH_4$ ), which are easily absorbed by plants, are introduced to the plant root zone. However, soils do not absorb the excess  $NO_3$  ions, which then move downward freely with drainage water and are leached into groundwater, streams and oceans (Ward *et al.* 2018). The degree of leaching is affected by soil type and structure. For example, sandy soil holds little water while clay soils have high water-retention rates; the amount of water used by the plants/crops; how much nitrate is already present in the soil (WQ262 Nitrogen in the Environment 2013). The level of nitrous oxide ( $N_2O$ ) in the Earth's atmosphere is increasing at a rate of 0.2 to 0.3% annually. Anthropogenic sources of nitrogen are 50% greater than from natural sources, such as, soils and oceans. Leaching of agricultural inputs such as fertilizers and manures, accounts for 75% of the anthropogenic source of nitrogen (Mosier *et al.* 1996). The Food and Agriculture Organization of the United Nations (FAO) estimates world demand for nitrogen fertilizers will increase by 1.7% annually between 2011 and 2015. Regional increases of nitrogen fertilizer use are expected to be 67% by Asia, 18% by the Americas, 10% by Europe, 3% by Africa and 1% by Oceania (FAO 2015).

### Phosphorus leaching

Phosphorus (P) is a key nutrient regarding the eutrophication of surface waters and has been shown to limit algae growth in lake environments. Loss of P from agricultural fields has long been recognized as one of the major threats to surface water quality (Ward *et al.* 2018). Leaching is an important transport pathway for P losses from agricultural fields is mainly flat areas with sandy soils or soils prone to special flow (Börling 2003). As opposed to nitrogen phosphorus does

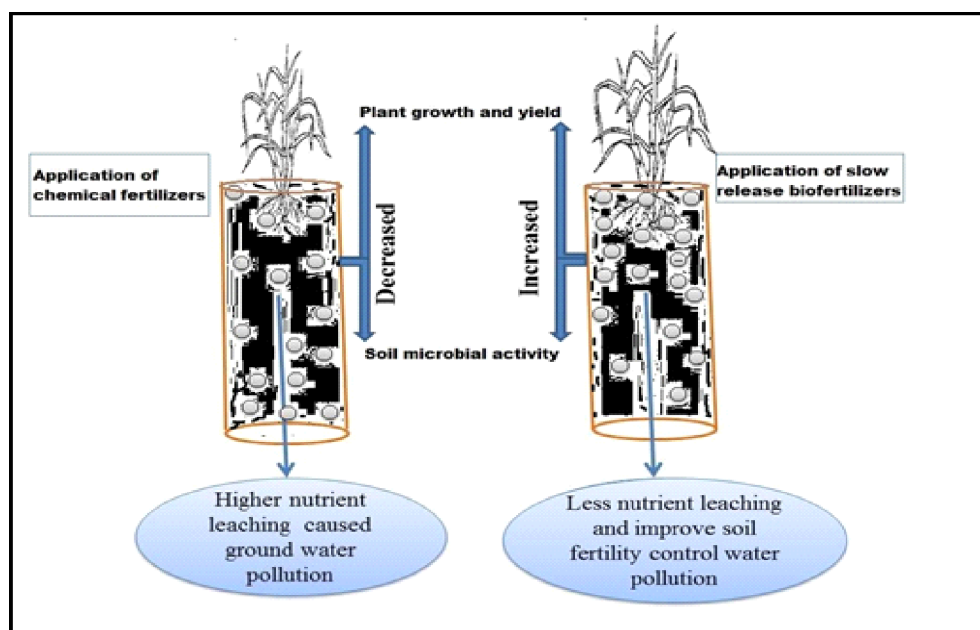


Fig 2: Role of chemical fertilizers and slow-release biofertilizers on growth, biomass and yield of plants and soil health.



interact with soil particles via adsorption and desorption. Important potential adsorption sites for P in soils are surfaces of iron and aluminum oxides or hydroxides such as gibbsite or ferrihydrite. Soils, especially those rich in such minerals do hence have the potential to store P added with fertilizer or manure. Adsorbed P stands in a complex equilibrium with P in the soil solution which is controlled by a multitude of different factors such as: the availability of adsorption sites; the concentration of phosphorus and other anions in the soil water solution; soil pH; soil redox potential (Börling 2003; Schoumans 2015).

Phosphorus will leach when this equilibrium is shifted such that either previously adsorbed P is released into the soil solution or additional P cannot be adsorbed anymore. Many cultivated soils have been receiving fertilizer or manure P in amounts frequently exceeding the crop demand and this often over decades. Phosphorus added to such soils leaches simply because most of the potential adsorption sites are occupied by P input from the past, so-called "legacy phosphorus" (Jarvie *et al.* 2013; Schmieder *et al.* 2018). Leaching of P may also because by changing chemical conditions in the soil. A decrease in the soils redox potential due to prolonged water saturation may lead to the reductive dissolution of ferric iron minerals that are important P sorption sites. Phosphorus adsorbed to these minerals is consequently released into the soil solution as well and may be leached. This process is of special concern in the restoration of natural wetlands that have previously been drained for agricultural production (Shenker *et al.* 2004; Zak and Gelbrecht 2007).

### Health impacts

Organic fertilizers and slow release bio fertilizers are cost effective and environment friendly fertilizers. It enhances plant growth and productivity of crops and also reduced environmental pollution such as soil, water and air. While due to excess use of chemical fertilizer on agricultural soil caused high levels of  $\text{NO}_3$  in water and it can adversely affect oxygen levels for both humans and aquatic systems. Human health issues include methemoglobinemia and anoxia, commonly referred to as a blue baby syndrome. As a result of these toxic effects, regulatory agencies limit the amount of  $\text{NO}_3$  permissible in drinking water to 45–50  $\text{mg l}^{-1}$ . Eutrophication, a decline in oxygen content of water, of aquatic systems can cause the death of fish and other marine species. Finally, leaching of  $\text{NO}_3$  from acidic sources can increase the loss of calcium and other soil nutrients, thereby reducing an ecosystem's productivity (Ward *et al.* 2018).

### CONCLUSION

Fertilizers are the major component for plant growth and development and its excess used in the agricultural field caused a negative impact on soil, water and air environment. For this reason, fertilizer will be lost from the soil, as well as caused pollution of surrounding soil, water and air environment. Therefore, slow release bio-fertilizer

Encapsulation technology protects the beneficial microorganisms with a carrier material and provides the improvement in nutrient uptake from the sources of sources of N, P and K to the soil and crops. As per long term use of bio-fertilizer leads to the build-up of nutrients in the soil thereby increasing the overall soil fertility and also control nutrient leaching from soil to water body.

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